European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME PERIOD: **92A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title Category: **C–5**

Unravelling the Intimate Properties of Photoionized Herbig-Haro Objects in the Orion Nebula

2. Abstract / Total Time Requested

Total Amount of Time: 0 nights VM, 11.6 hours SM

We propose to carry out the first systematic spectroscopic analysis of a sample of photoionized Herbig-Haro objects located in the Orion Nebula. The high resolution provided by UVES (∼6.5 km s^{-1} at 1″ slit width) will de-blend the gas flow component from the ambient emission of the nebula. With these observations we will investigate the properties of the gas at the flows such as their excitation mechanism, physical conditions, chemical abundances, ionization structure or localization in the nebula. Additionally, we will characterize the physical properties of localized heating zones at the leading working surface of the flows and its impact on chemical abundance determinations. Finally, the role of high-velocity gas flows will be investigated in the context of shock-induced destruction of dust particles, an issue only addressed theoretically so far.

3. Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	92	UVES	11.6h	dec	g	1.0	CLR	s	

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

6. Principal Investigator: Adal Mesa-Delgado, adalfis@gmail.com, CL, Pontificia Universidad Catolica de Chile,Dept of Astronomy & Astrophysics

6a. Co-investigators:

C.	Esteban	Instituto de Astrofisica de Canarias, Headquarters,E
J.	García-Rojas	Instituto de Astrofisica de Canarias, Headquarters,E
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7. Description of the proposed programme

A – Scientific Rationale: Herbig-Haro (HH) objects are manifestations of collimated supersonic ejections of material powered by young pre-main-sequence stars. In last decades, and especially with the launch of the HST, many HH objects have been identified in the central part of Orion Nebula (e.g. O'Dell et al. 1997, AJ 114 730), the Huygens region, revealing a wealth of complex structures that provides probes for interactions between gas flows and the ambient gas (Hu 1996, AJ 212 2712). Due to its proximity and high surface brightness, *the Orion Nebula is the best laboratory so far to investigate these interactions in photoionized media*. HH objects are in general dominated by shock excitation. In the Orion Nebula, O'Dell et al. (1997) observed that several of the flows immersed in the Huygens region appear very bright in [O III], which is atypical of most HH flows that show much lower ionization. This atypical behavior is due to Orion flows are mainly dominated by photoionization from the main ionizing source of the Trapezium cluster, θ^1Ori C, though a partial contribution of shocked gas could still exist. Understanding line ratios in HH objects requires distinguishing shocked from photoionized gas before one determines their physical conditions and chemical composition. However, there is a major lack of works devoted to this kind of studies. Most spectroscopic studies carried out in the Orion HH flows has been mainly focused on their gas kinematics (e.g. Henney et al. 2007, AJ 133 2192; O'Dell & Henney 2008, AJ 136 1566). Also, the most detailed studies of their physical properties as well as their effects on the surrounding media have been mainly addressed theoretically (e.g. Raga et al. 2009, RMxAC 36 186). To correct this situation, the present proposal will carry out the first systematic and detailed analysis of photoionized HH objects in the Orion Nebula. With this proposal, we will characterize the properties of selected gas flows and study the "environmental" dependences (e.g. flow velocity or distance to the ionizing source) of these properties . The effects of the HH flows on the surrounding media will be also addressed, providing new constraints to theoretical studies of these interactions.

The only physical and chemical analyses of photoionized HH objects in the Orion Nebula have been performed by Blagrave et al. (2006, ApJ 644 1006) from echelle spectroscopy in the range 3500-7500 Å at the 4m Blanco Telescope, and Mesa-Delgado et al. (2009a, MNRAS 395 855) using UVES@VLT in the range 3100-10400 Å. These authors studied the third bow shock that shapes HH 529, HH 529-III, and the south knot of the prominent HH 202, HH 202-S, respectively. The high spectral resolution (R$\sim$30000) of the observations allowed them to separate the kinematic component of the high-velocity gas emission from the ambient gas emission. HH 202-S observations were much deeper than those of HH 529-III and its spectra had a very high signal-to-noise ratio (see Fig. 1a). Using shock diagnostic diagrams based on [O III]/Hα and [N II]/Hα ratios, both works concluded that the spectrum of the gas flows are mainly dominated by photoionization from θ^1Ori C. This permitted to determine the physical conditions from several diagnostic ratios (e.g. [S II] 6717/6731, [Cl III] 5717/5737 or [O III] 5007/4363) and the chemical composition of the HH gas using the standard methods for photoionized nebulae. Particularly, these authors found: (a) a large density contrast between the gas flow (HH 529-III$\sim$13000 cm^{-3} and HH 202-S$\sim$17400 cm^{-3}) and the ambient gas ($\sim$3500 cm^{-3}); and (b) an O abundance in HH 529-III of 0.2 dex higher than in the ambient gas of the Orion Nebula (8.50 dex; Esteban et al. 2004, MNRAS 355 229), while HH 202-S shows similar values. Analyzing the distribution of the ionic species with respect to their ionization potential, the ionization structure of these objects was also studied finding that HH 529-III is matter-bounded and HH 202-S is ionization-bounded. Interestingly, in the case of HH 202-S this last result implies that this HH object has trapped an ionization front and this fact allows to constrain its spatial localization in the the 3D structure of the Orion Nebula. For the first time, Mesa-Delgado et al. determined the physical separation between HH 202-S knot and θ^1Ori C –of 0.14$\pm$0.05 pc– pointing out that this flow is embedded in the Huygens region.

Models of photoionized HH flows (Raga & Reipurth 2004, RMxAA 40 15) predict that the electron temperature, T$_e$, along an HH object is the typical of a gas in photoionization equilibrium –about 10^4 K– but shows a localized increase at the leading working surface of the bow shock due to shock heating. This zone is narrow and precedes the high-density shocked gas behind the working surface of the gas flow. Very recently, *this structure has been discovered in the HH 204 object of the Orion Nebula* by Núñez-Díaz et al. (2012, MNRAS 421 3399) making use of integral-field spectroscopy at spatial scales of 1"$\times$1" with PMAS@3.5m CAHA (Fig. 1b). A similar narrow arc was also observed in a previous study of HH 202 (Mesa-Delgado et al. 2009b, MNRAS 394 693), but it was not reported (Fig. 1c). Nuñez-Díaz et al. quantify that the narrow shock-heated zone shows a T$_e$ enhancement of about 1000 K with respect to the ambient gas. According to their analysis, the compression and heating of the gas due to the presence of high-velocity flows is affecting the chemical abundance determinations due to: (a) an overestimation of the collisional de-excitation effects on emission lines arising from levels with low critical densities; and (b) the use of too high T$_e$ values for deriving abundances due to contamination from emission of the leading working surface. It is fundamental to investigate the importance of these disturbing effects into the determination of chemical abundances in the Orion Nebula and, in general, H II regions, especially for those objects where small-spatial scale phenomena cannot be resolved (i.e. extragalactic objects).

The study of photoionized HH objects is essential and unique to address the complex issue of destruction of dust particles by shock waves as Mesa-Delgado et al. (2009a) showed in the analysis of HH 202-S. Refractory elements like Fe, Ni, Cr or Ca are expected to be largely depleted in H II regions, though theoretical studies have shown that fast shocks –as those typical in HH objects– should efficiently destroy dust grains (e.g. Mouri & Taniguchi

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

2000, ApJ 534 L63). Works in non-photoionized HH flows show evidence for decrease in the amount of Fe depletion as determined from the analysis of [Fe II] lines (e.g. Nisini et al. 2005, A&A 441 159), or enhancements in the Ca gas-phase abundance from the analysis of [Ca II] 7291/[S II] 6731 ratio (e.g. Podio et al. 2009, A&A 506 779). However, non-photoionized HH flows are mainly dominated by shocks making complex the analysis of their spectrum. In this sense, photoionized HH objects has the clear advantage that their chemical content can be determined using the classical methods applied to ionized gas. HH 399 is the first precedent of a fully ionized HH object where an overabundance in Fe was detected and related to dust destruction (Rodríguez 2002, A&A 389 556). The study of HH 202-S performed by Mesa-Delgado et al. showed that the gas-phase abundances of Fe and Ni increase in the same proportion, 30-50%, after the passage of the shock wave. In addition and only in the gas flow component, a substantial number of emission lines of refractory heavy-element ions as [Ca II], [Cr III], [Co II], [Co III], [Ti III] and, possibly, [Cr IV], [Co IV], [Mn II] and [V II] were detected. These results combined with those of tailored photoionization models provided ***the first observational evidence of dust destruction in a photoionized HH object***. It is clear that Fe and Ni abundance determinations in a larger sample of HH objects –with different spatial velocities and ionization conditions– will permit to obtain important constraints for a better understanding of the mechanisms of dust grain destruction and their ultimate nature.

B – Immediate Objective: The present proposal is predicated on carrying out the first comprehensive physical and chemical analysis of a carefully selected sample of photoionized HH objects in the Orion Nebula. The targets were chosen attempting to their different distances ($\sim$10″-70″) to the main ionizing source of the Trapezium cluster and to cover an ample range of spatial velocities, between 70 and 130 km s^{-1}. Using the UVES spectrograph in the range 3100-10400 Å with a spectral resolution R$\sim$45000 ($\sim$6.5 km s^{-1} at 1″ slit width), we will resolve the kinematic components associated with the gas flow emission from the ambient gas emission. With these high-quality dataset we will investigate:

(a) physical and chemical properties of the gas flows (excitation mechanism, ionization structure, physical conditions, chemical abundances);

(b) the first characterization of the predicted high-T$_e$ arcs and their global effect on the chemical composition determination of the nebula;

(c) dust destruction patterns (only theoretically studied so far in HH objects before Mesa-Delgado et al.'s study).

(d) and, finally, the correlation of the previous quantities with the distance to θ^1Ori C and with the gas flow velocities.

Attachments (Figures)

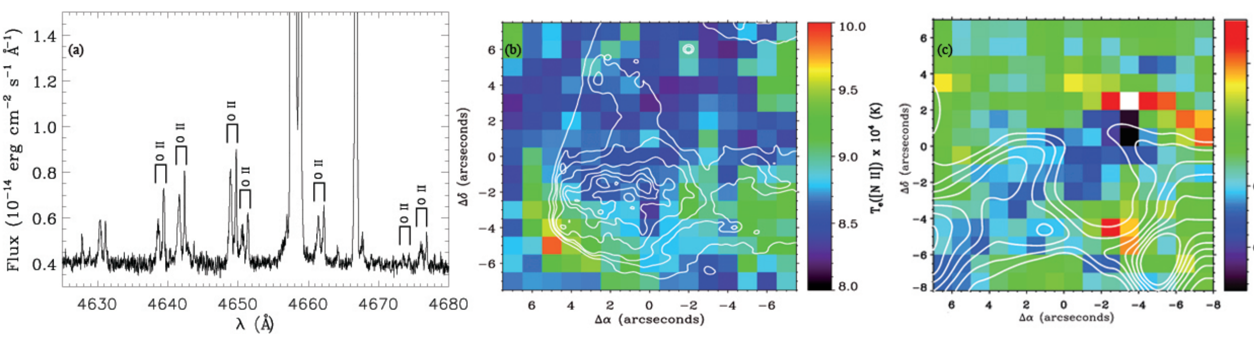

Fig. 1: (a) High-resolution UVES spectrum of HH 202-S de-blending the gas flow emission (left component) from the ambient gas (right component) of each emission line of multiplet 1 of O II, whose emission flux is 0.001×F(Hβ). (b,c) Spatial distribution maps of T$_e$([N II]) with Hα contours over-plotted for HH204 (b) and HH202 (c). High-T$_e$ arcs are located along the narrow areas at the leading working surface of the gas flows: at the lower-left corner for HH 204 (b) and near the upper-right corner in HH 202 (c).

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: Considering the high surface brightness of the Orion Nebula, there is not a strict restriction on the lunar phase. However, grey nights are preferred to increase the quality of the data.

Time Justification: (including seeing overhead) Considering the surface brightness of each HH object and our previous observations of HH 202, we have estimated the following exposure times: 3×180 s for DIC1 and 3×620 s for DIC2. Also shorter exposures, of the order of 5 s for DIC1 and 10 s for DIC2, would be necessary to avoid saturation of the strongest lines. Then, we have calculated an exposure time per object of about 2415 s (0.67 h). Furthermore, we have to add the time spent on overheads: a)telescope presetting: 360 s; b)acquisition of the guide star: 120 s; c)target acquisition and centering the slit: 300 s; d)readout of the CCD (fast mode) 8 exposures × 40 s = 320 s; and e)change of setup from DIC2 to DIC1: 60 s. Then, the final exposure time per object will be 3600 s (1 h). The total exposure time spent observing the sample of 8 objects would be: 28800 s (8 h).

The proposal would require the observation of a flux calibration star: LTT3218 (m_V = 11.86). The exposure time would be: 500 s in DIC1 and DIC2. The overheads related to this observation: telescope presetting (360 s), target acquisition and centering the slit (120 s), readout of 2 exposures in fast mode (80 s) and one change of setup from DIC1 to DIC2 (60 s). Then, the total time spent on observing the standard star would be: 1000 s + 620 s (overheads) = 1620 s (0.45 h).

Based on the observing time needed per object, we plan that each object requires one observing block (OB). In the extreme case that each OB is executed in different nights, the OB associated with the standard star should be also executed. Therefore, the total time spent in the proposal will be in this conservative case: 8 h (objects) + 8(objects)×0.45 h (standard) = 11.6h.

8a. Telescope Justification:

Our experience with the analysis of HH 202-S ensures us that UVES@VLT offers the highest efficiency in the spectral range 3100-10400 Å using moderate exposure times in the Orion Nebula. Furthermore, these exposure times will allow us to observe a representative sample of HH objets needed to address the science goals of our study. Additionally, the spectral coverage provided by UVES will give us access to all diagnostics ratios available in the optical range such as [S II] 6717/6731, [Cl III] 5517/5537, [S II] (6717+31)/(4068+76), [O III] 5007/4363 or [N II] 6584/5755, which are needed to carry out the characterization of the physical conditions of the gas flows.

8b. Observing Mode Justification (visitor or service):

The observations are rather simple and, therefore, very appropriate for Service Mode.

8c. Calibration Request:

Special Calibration - We will require the observations of a spectrophotometric standard star for a proper flux calibration.

9. Report on the use of ESO facilities during the last 2 years

• 091.C-0481 - (PI: A. Mesa-Delgado) *"Characterizing Fundamental Parameters of Orion Proplyds from High-Spatial Resolution NIR Spectroscopy"* (SINFONI). Phase II approved, observations are in the queue.
• 091.A-0053 - (PI: T. Puzia) *"To Boldly Go Where No One Has Gone Before! – VLT/XSHOOTER Spectroscopic Confirmation of the most Distant Gravitational Lens-Source Pair: A $z \approx 8$ Galaxy lensed by a $z \approx 1.7$ Deflector System"* (XSHOOTER). Phase II approved, visitor-mode observations scheduled.
• 091.D-0464 - (PI: T. Puzia) *"Testing for the Existence of Massive Population-III Stars with Stellar Archaeology"* (CRIRES). Phase II approved, observations are in the queue.
• 090.D-0265 - (PI: J. García-Rojas) *"Tracing nucleosynthesis in AGB stars: s-process enrichments in planetary nebulae"* (UVES). So far approximately 30% of the service-mode observations have been executed by the time of this deadline.
• 090.D-0368 - (PI: T. Puzia) *"The Light-Element Enrichment in Magellanic Cloud Star Clusters featuring extended Main-Sequence Turnoff Regions"* (FLAMES). 30% of data taken, program rolled-over into P91.

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

No, they are not.

9b. GTO/Public Survey Duplications:

None.

10. Applicant's publications related to the subject of this application during the last 2 years

W. Henney, et al., 2013, MNRAS, 428, 691: Mapping the complex kinematics of LL objects in the Orion nebula.

A. Mesa-Delgado, M. Nuñez-Díaz, **C. Esteban**, et al., 2012, MNRAS, 426, 614: Ionized gas diagnostics from protoplanetary discs in the Orion Nebula and the abundance discrepancy problem.

M. Nuñez-Díaz, **A. Mesa-Delgado**, **C. Esteban**, **J. García-Rojas**, et al., 2012, MNRAS, 421, 3399: Exploring the effects of high-velocity flows in abundance determinations in H II regions: bidimensional spectroscopy of HH 204 in the Orion nebula.

J. García-Rojas, et al., 2012, A&A, 538, 54: Analysis of chemical abundances in planetary nebulae with [WC] central stars. I. Line intensities and physical conditions

A. Mesa-Delgado, M. Nuñez-Díaz, **C. Esteban**, et al., 2011, MNRAS, 417, 420: Integral field spectroscopy of selected areas of the Bright bar and Orion-S cloud in the Orion nebula

Á.R. López-Sánchez, **A. Mesa-Delgado**, et al., 2011, MNRAS, 411, 2076: The ionized gas at the centre of IC 10: a possible localized chemical pollution by Wolf-Rayet stars

S. Simón-Díaz, **J. García-Rojas**, **C. Esteban** et al., 2011, A&A, 530, 57: A detailed study of the H II region M 43 and its ionizing star

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	HH 514	05 35 16.95	-05 23 34.14	1.44			355^o,+135,131	
A	HH 518	05 35 16.30	-05 23 41.59	1.44			39^o,+76,74	
A	HH 523	05 35 18.20	-05 23 30.22	1.44			80^o,−45,102	
A	HH 529-I	05 35 15.95	-05 23 53.21	1.44			50^o,−30,78	
A	HH 529-	05 35 17.79	-05 23 57.32	1.44			100^o,II:−31,108; III:−30,69	
A	HH 202-N	05 35 11.81	-05 22 48.02	1.44			336^o,−21,67	
A	HH 203	05 35 22.19	-05 25 04.54	1.44			139^o,−46,77	
A	HH 204	05 35 22.74	-05 25 19.47	1.44			137^o,−18,92	

Target Notes: In the table, we present the sample of 8 photoionized HH objects –ordered by increasing distance to θ^1Ori C– that we propose to observe including: several micro-jets that are ejected from nearby protoplanetary disks as HH 514 and 523; well defined bow shocks as HH 518 and 529; and, finally, the prominent HH 203, HH 204, and the north knot of HH202, -N. These HH objects were selected attempting to their appearance brightness, distances to θ^1Ori C and spatial velocities. The surface brightness of the targets is similar to that of HH 202, where we successfully performed the analysis proposed in this research project. They are mainly located in the central area of the nebula, with distances between $10''$ and $70''$ from θ^1Ori C. Their spatial velocities range from 70 to 130 km s^{-1} with the aim of defining an ample range of velocities in which the velocity dependence of certain processes such as dust destruction can be investigated. For the selected objects, the proposed UVES configuration will resolve both ambient and gas-flow kinematic components in all the sample, even in the case of faint emission lines (Fig. 1a). The coordinate columns shown in the table are the central coordinates of the slits. In "Additional Info":

- First value: the position angle (PA) of the slits measured from north to east and fixed along the moving direction of the gas flows to spatially cover the shock-heated zones at their leading working surface.
- Second value: the Hα heliocentric radial velocity in km s^{-1} of the HH objects, which has helped us to select the sample objects in order to ensure that the gas flow emission will be de-blended from the ambient gas, considering that the ambient gas has an Hα heliocentric velocity around 15 km s^{-1}. Our reference, HH 202-S, has a radial velocity about −39 km s^{-1}.
- Third value: the spatial velocity in km s^{-1} in the three-dimensional space, which covers a range from 67 to 131 km s^{-1} allowing to investigate the effects of high-velocity flows in the chemical composition of the ionized gas, the formation of high-T_e arcs, the gas compression, the correlation between the gas flow velocities and the destruction of dust particles.

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
92	UVES	A	DIC-1	Standard setting: 346+580
92	UVES	A	DIC-2	Standard setting: 437+860